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Correlated Inheritance in Wheat III Federation XIII C 18

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CORRELATED INHERITANCE IN WHEAT III

FEDERATION X III C 18 (DICKLOW X SEVIER HYBRID)

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Introduction

Several wheat characters have been shown to exhibit rather complicated inheritance. Examples are such characters as culm length, spike density, and awn classes. This paper reports a study of the inheritance and of the correlated inheritance of these and some other plant characters in a cross between a hybrid of Dicklow X Sevier (III C 18) with Federation.

Literature

The literature which applies to inheritance of the wheat characters herein reported has recently been quite thoroughly reviewed by Clark (1) by Hayes and Garber (2) and by Stewart (3). On this account only references which bear directly on the particular problems under discussion are cited.

Description of Parents

Federation has been rapidly growing in importance in Utah and Idaho as an irrigated wheat. This is largely due to its high yielding ability and to its habit of not lodging under irrigation. It has a short stiff straw. Its glumes are dark bronze in color. It is classed as an awnless wheat, yet short tip awns or beaks are usually present.

Different characters were measured on the 37 parent rows which were grown with the F_3 progenies. The averages for these are given below:

Length of longest culm to base of spike	=	75.34 Cm.
Spike density - length one rachis internode	=	5.02 mm.
Length of awn	=	5.05 mm.
Neck thickness	=	2.40 mm.
Number of culms per plant	=	10.13 mm.

III C 18 was developed by Stewart at the Utah Experiment Station. It is one of the high yielding hybrid stains selected from the Sevier X Dicklow cross. It inherits to some extent, at least, the weak straw of its Sevier parent.

IIIC 18 has white glumes or chaff. It is a fully awned wheat.

Measurements of plant characters of IIIC 18 in the 37 parent rows give the following averages.

Length of logest culm to base of spike	=	91.96 cm.
Spike density - length one rachis internode	=	2.62 mm.
Awn length	=	73.07 mm.
Neck thickness	=	2.34 mm.
Number of culms per plant	=	9.46

These measurements show IIIC 18 to have a culm length of about 17 cm. more than Federation. Also the spike is nearly twice as dense. The awns have considerable length. In neck thickness and number of culms per plant the parents are almost alike.

Experimental Procedure

The cross between a pure line of Federation and the pure line IIIC 18 was made in 1924 at Logan, Utah. The F_1 plants were grown in 1925. In 1926 the F_2 families were grown. One of the most vigorous of these families was chosen to contimue with. The family chosen contained 354 plants. Each of these plants was classified according to awn class, glume color, and spike density. Length of longest culm and length of ten rachis internodes were measured and recorded. Grain from each plant seeded an F_3 progeny row in 1927. Forty to fifty kernels spaced three inches apart in each F_3 row were planted except when an F_2 plant furnished fewer kernels than this. The rows were spaced one foot apart.

As just remarked, each F_2 plant seeded one F_3 progeny row. This made it possible to use the breeding behavior of the F_3 progenies as the basis for classifying the F_2 plants. This method is thought to be superior to the method of classifying the F_2 material especially when studying complicated characters and characters which exhibit intermediate inheritance.

As will be pointed out later an accurate study of awn classes when made in the F_2 generation was impossible. Other characters also yield much more reliable data when the F_3 progenies are studied rather than the F_2 plants.

After each tenth progeny row the parental varieties Federation and IIIC 18 were planted side by side. These parental rows were spaced and planted in the same manner and at the same time as were the progeny rows. In all there were 37 parental pairs. This procedure made it possible to study progeny characters in connection with parent characters.

When the grain was ripe each F_3 row was carefully harvested by pulling individually the plants in the row. The row was bundled, tied, and tagged. The material was worked during the winter months in the laboratory.

Observations and Measurements

The data were secured for each F_3 progeny by classifying and measuring each plant in the progeny. The usual number of plants in each progeny ranged from 20 to 35. In some progenies there were fewer than this and in many there were 40 or more. Each plant in each of the 37 pairs of parental rows was observed and measured in the same manner.

The following observations and measurements were recorded:

1. Glume color; bronze or white.

2. Length of longest culm. This measurement was obtained by placing the roots of the plant against a foot board nailed to a table board which was

marked in centimeters. The longest culm on the plant was measured to the base of the spike.

3. Number of culms; obtained by count. Immature or second growth culms were not counted.

4. Spike density. Ten rachis internodes located within the middle section of the spike were measured in millimeters. In the discussion and tables which follow the length of one rachis internode is used. This figure is obtained by moving the decimal point one place to the left.

5. Awn length; measured in millimeters. As far as possible, the longest awn on each plant was measured.

6. Neck thickness in millimeters was measured with callipers just below the spike.

7. Awn classes were determined by eye classification. Four awn classes were chosen as described by Stewart (3). Length of awn and location of awns on the spike were used as bases of classification. No. 1 awns = no awns or only beaks at the apex; No. 2 awns = short awns located at apex; No. 3 awns = part length apical awns and shorter awns located along down the spike; No. 4 awns = fully awned.

Study of the Data

As already stated each plant in each F_3 progeny was observed and measured for the characters which were being considered. The classification of the progeny depended then on the natures of the plants within the progeny. For the observed character of glume color and awn class the progenies were easily arranged in their homozygous and heterozygous classes by observing the data recorded for the plants within the progenies. The mean value of each progeny was calculated for the measured characters.

The data were then studied genetically and by correlation tables.

Glume Color

Eighty-two F_3 progenies were homozygous for bronze glumes, 176 were heterozygous for color of glumes, and 96 were homozygous for white glumes. These numbers suggest the 1:2:1 ration which has been previously observed by several other workers. There is probably a single factor difference for color of glumes. The goodness of fit on this hypothesis is shown in Table I, $X^2 =$ 1.1186 and P= 0.5782 which is a good fit.

Awn Classes

Fig. 1 shows typical heads for each of four homozygous awn classes. Figs. 2 to 5 show homozygous F_3 progenies for awn classes 1, 2, 3, and 4. Besides these homozygous classes there were five segregating classes of progenies. Those segregating for awn classes 1 and 2; those for awn classes 1, 2, and 3; those for awn classes 1, 2, 3, and 4; those for awn classes 2, 3 and 4; and those for awn classes 3 and 4.

This makes nine genotype classes into which the F_3 progenies arranged themselves in the following numbers.

Homyzygous awn 4 = 23 progenies

Segregating awn 3,4 = 38 "

Segregating awn 2,3,4= 43 "

Segregating awn 1,2,3,4 = 81 "

Homozygous awn 3 = 24

Segregating awn 1,2,3 = 46


Federation x III C 18
Class 1
Class 2
Class 3
Class 4
Homozygous F3's for Awn Classes

Fig. 1

Table 1. Goodness of fit of three groups of F_3 progenies for glume color compared with a 1:2:1 ratio.

(Grown in 1927 at Logan, Utah)

Group	C	O	C - O	$(C - O)^2$	$\frac{(C - O)^2}{C}$
Homozygous Bronze	88.5	82	6.5	42.25	.4774
Heterozygous	177.0	176	1.0	1.00	.0056
Homozygous White	88.5	96	7.5	56.25	.6356

$$X^2 = 1.1186$$

$$P = .5782$$

Homozygous awn 2 = 24 progenies

Segregating awn 1,2 = 50 "

Homozygous awn 1 = 25 "

These numbers suggest a ratio of 1:2:2:4:1:2:1:2:1 which would theoretically be obtained when two factor differences segregate independently. The goodness of fit on this basis is calculated in Table 2, $X^2 = 3.0961$ and $P = 0.9270$ which indicates an extremely good fit.

Stewart (3) has suggested two linked factors with 35 per cent crossing over to explain the awn class inheritance in Sevier X Federation crosses and in a cross between a Sevier X Dicklow hybrid (G-149) and Federation. (4)

The awn class inheritance in the Federation X IIIC 18 can be explained on a two factor difference only where independent segregation rather than linkage occurs. This suggests that the hybrids IIIC 18 and G-149 both derived from Federation X Sevier crosses and both fully awned have different genetic constitutions for awn classes. One explanation which might be offered for this difference is that the Sevier variety of wheat is a composite of quite variable lines. One Sevier pure line when crossed with Dicklow may have given the strain which behaves as G-149 while another Sevier pure line corssed with Dicklow may have given the IIIC 18 strain which behaves differently.

Since Federation X IIIC 18 shows no linkage the assumption is here made that at least one of the awn factors in IIIC 18 is different from that in G-149. The factors designated for the Federation X G-149 cross (4) were $A_{(a)}$ and $T_{(t)}$. For the Federation X IIIC 18 cross let it be supposed that the factor A is the same as in the above cross but that T is not operative and is

Table 2. Goodness of fit of nine awn genotype classes of F_3 progenies when compared with a 1:2:2:4:1:2:1:2:1 ratio which would theoretically be obtained when two factor differences segregate independently.

(Grown in 1927 at Logan, Utah)

C	O	C - O	$(C - O)^2$	$\frac{(C - O)^2}{C}$
22.125	23	.875	.7656	.0346
44.25	38	6.25	39.0625	.8828
44.25	43	1.25	1.5625	.0353
88.50	81	7.50	56.2500	.6356
22.125	24	1.875	3.5156	.1589
44.25	46	1.75	3.0625	.0692
22.125	24	1.875	3.5156	.1589
44.25	50	5.75	33.0625	.7472
22.125	25	2.875	8.2656	.3736

$X^2 = 3.0961$

$P = .9270$

designated as t but that the factor B acts the same as T except that it is not linked with A. The awn classes would then be designated as follows:

Awn 4 = AA tt BB

Awn 3 = AA tt bb

Awn 2 = aa tt BB

Awn 1 = aa tt bb

Table 3 gives the nine F_2 awn class genotypes their expected ratio and their breeding behavior based on the above assumptions.

It is interesting to note at this point the resulting numbers in the four awn classes when the F_2 population was classified. The 345 F_2 plants were classified in 1926-27 before planting time just as were the F_3 progenies a year later. The numbers obtained for each of the awn class groups were as follows:

Awn 4 = 49 F_2 plants

Awn 3 = 35 F_2 Plants

Awn 2 = 106 F_2 Plants

Awn 1 = 164 F_2 Plants

This data when compared with the F_3 data indicates how unreliable would be awn inheritance data when secured from the F_2 generation.

<u>Length of Longest Culm</u>

There was considerable difference between the average culm length of the two parent plants. When the means of the 37 parent rows were averaged the following figures were obtained. Federation = 75.34 cm. and IIIC 18 = 91.96 cm. The IIIC 18 parent averages 16.62 cm. more in culm length than the Federation parent. With this quite considerable difference between the parents it could be expected that there would be a segregation in the F_2 generation and

Table 3. F_2 awn class genotypes, their expected proportions on an independent segregation basis, and their expected breeding behavior.

	Genotype	Numbers Expected	Breeding Behavior
(1)	AA tt BB	1	Breed true for awn 4
(2)	AA tt Bb	2	Segregate for awn 3, 4
(3)	Aa tt BB	2	Segregate for awn 2, 3, 4
(4)	Aa tt Bb	4	Segregate for awn 1, 2, 3, 4
(5)	AA tt bb	1	Breed true for awn 3
(6)	Aa tt bb	2	Segregate for awn 1, 2, 3
(7)	aa tt BB	1	Breed true for awn 2
(8)	aa tt Bb	2	Segregate for awn 1, 2
(9)	aa tt bb	1	Breed true for awn 1

that there should be a tendency for the F_3 progenies to inherit the culm length of their respective F_2 plants.

Table 4 shows the range in mean culm length for the parental rows and for the F_3 progenies. The parental classes do some overlapping but the shortest Federation row is four classes below the shortest IIIC 18 row. And the longest IIIC 18 row is five classes above the longest Federation row. Out of the 354 F_3 progenies the longest IIIC 18 row is nearly recovered in one progeny. The longest IIIC 18 = 109.00 cm. and longest F_3 progeny = 107.75 cm. The shortest Federation row is also practically recovered in justone F_3 progeny. The shortest Federation row is 57.62 cm. in culm length and the shortest F_3 progeny is 59.20. The range of the progenies, then essentially covers the range of the parents and the distribution resembles that of a normal curve (Fig. 6). Culm length inheritance is probably complicated by several multiple factors.

The culm length of the F_2 plants was correlated with the mean culm length of their respective F_3 progenies. ~~Table~~ ____ . A correlation coefficint of + . 4316 ± .0291 was obtained. This constant is 14.8 times its probable error. This significant correlation obtained between the F_2 plants and their F_3 progenies indicates that culm length inheritance is displayed in this cross. Except for the great influence of environmental factors on a character such as height of plant, the correlation could be expected to be higher than that obtained.

Number of Culms

The two parents average essentially the same number of culms per plant (Federation = 10.13 and IIIC 18 = 9.46). Correlation coefficients were calculated between number of culms and all other plant characters studied. In every case the probable error was almost as large as its constant. In this cross

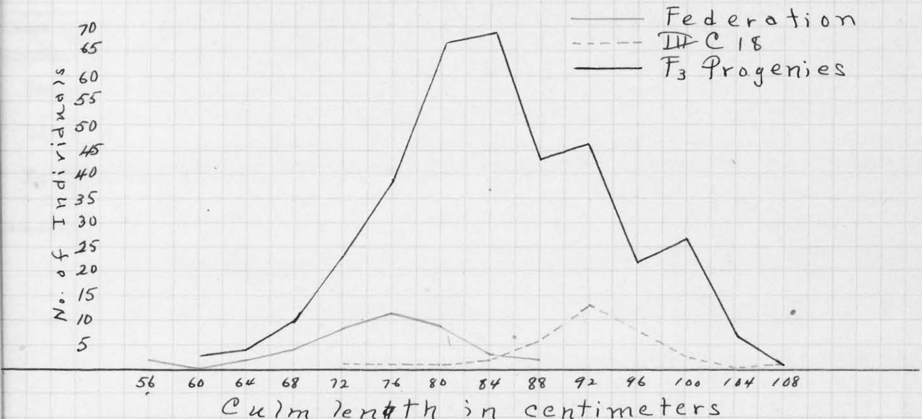

Fig. 6 — Culm length curves of Federation and III C 18 parents and F_3 progenies.

Table 4. Culm length classes of the means of F ederation and III C 18 parental rows and of the F_3 progenies.

(Grown in 1927 at Logan, Utah)

Culm Length Classes in Centimeters	56	60	64	68	72	76	80	84	88	92	96	100	104	108	Total
Federation	1		1	3	8	11	9	3	1						37
III C 18					1	1	1	2	6	13	8	4		1	37
F_3 Progenies		1	3	10	24	35	67	68	43	46	22	27	7	1	354

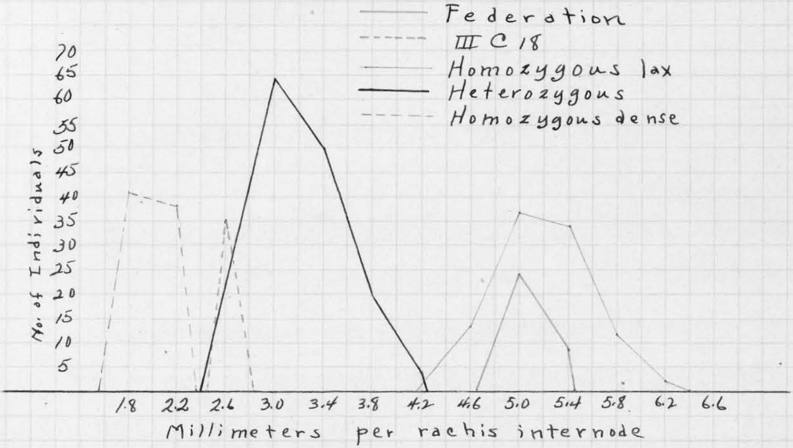

Fig. 7 – Spike density curves of Federation and III C 18 parents, and of three F_3 progeny groups (homozygous lax, heterozygous, and homozygous dense)

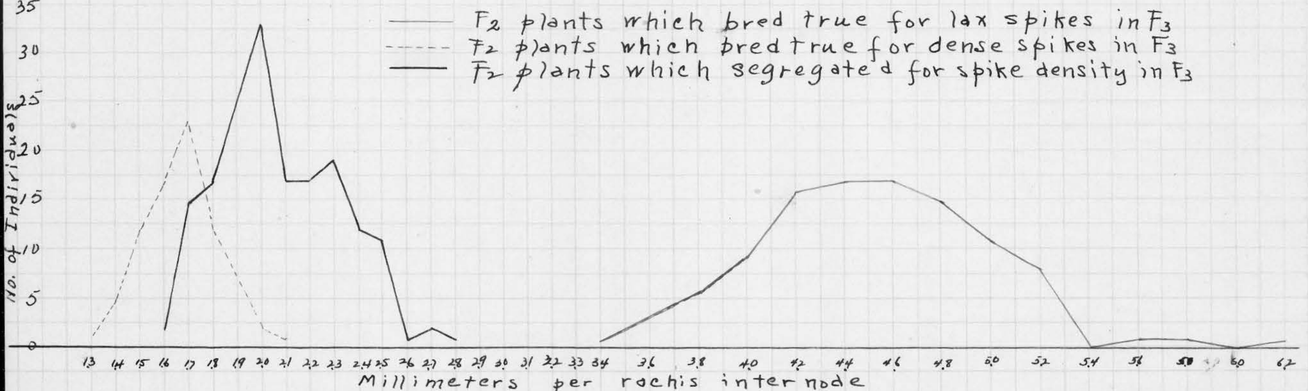

Fig. 8 - Spike density curves of F_2 plants which in F_3 segregated for the three major spike density groups

then, there seems to be no segregation or inheritance in stooling ability as indicated by number of culms.

Spike Density

As before mentioned the F_3 breeding behavior was used as the basis of determining the spike density inheritance. The mean length of 10 rachis internodes of each F_3 progeny and of each parent row was calculated. The coefficients of variability (C.V.) were also calculated. Table 5 shows the mean spike density classes and the coefficient of variability classes of the parent rows and of the three groups of F_3 progenies; homozygous dense, heterozygous, and homozygous lax.

Fig. 7 shows the curves plotted for these same groups.

Fig. 9 illustrates the range in spike densities.

The coefficients of variability (C.V.) of the IIIC 18 parent rows range from 7.47 per cent to 14.65 per cent with a mean of 9.81 per cent. The coefficients of variability (C.V.) of the Federation parent rows range from 4.90 per cent to 14.14 per cent with a mean of 10.59 per cent.

For the homozygous dense F_3 progenies the range in coefficients of variability (C.V.) was from 4.78 per cent to 18.12 per cent with a mean of 10.62 per cent.

The range for the heterozygous F_3 progenies was from 17.19 per cent to 61.28 per cent with a mean of 40.77 per cent. The particular progeny which gave the lowest coefficient of variability (17.19 per cent) had in it only 13 plants. It chanced that the range among these 13 plants was small. It is probable that the coefficient of variability is considerably lower than it would have been if more plants had grown. The next lowest coefficients of variability are 27.42 per cent and 27.74 per cent. The progenies exhibiting these per cents had in them 22 and 29 plants respectively. The actual range may therefore be considered to be from 27 per cent to 61 per cent.


Federation X III C 18
5.02 mm.
2.62 mm
6.35 mm.
4.35 mm.
2.35 mm.
1.63 mm.
Parents
Homozygous Lax
Homozygous Dense

Fig. 9

Table 5. Spike density classes of the means of parental rows and of F_3 progenies and coefficients of variability(C.V.) classes of the individual rows of each parent and of the three groups of F_3 progenies(homozygous dense, heterozygous, and homozygous lax).

(Grown in 1927 at Logan, Utah)

	Spike Density Classes															
	18	22	26	30	34	38	42	46	50	54	58	62	66	Total	C.V. Classes	Total No. Individuals
Federation										1				1	4	
									12	5				17	8	37
								4	12	2				18	12	
								1						1	16	
Total								5	24	8				Mean	9.81	
III C 18			15	1										16	8	
			18	1										19	12	37
			2											2	16	
Total			35	2										Mean	10.59	
	2													2	4	
Homozygous	22	11												33	8	
Dense	16	22												38	12	80
	2	4												6	16	
		1												1	20	
Total	42	38												Mean	10.62	
				1										1	16	
															20	
															24	
Heterozygous			1	2			1							4	28	
				4	5	3	1							13	32	
		1	5	10	8	6								30	36	
		1	11	20	19	4	1							56	40	171
		1	8	16	9	4								38	44	
			3	8	8	2								21	48	
				3	1	1								5	52	
			1											1	56	
			1				1							2	60	
Total		3	30	64	50	20	4							Mean	40.77	
									1					1	4	
Homozygous							2	8	18	25	7	2		62	8	
Lax							2	5	18	8	5		1	39	12	103
										1				1	16	
Total							4	13	37	34	12	2	1	Mean	9.56	

The coefficient of variability (C.V.) range in the homozygous lax group was from 5.67 per cent to 15.16 per cent with a mean of 9.56.

The means of the coefficients of variability (C.V.) of the two homozygous groups are nearly the same as the means of the parents. The range is also approximately the same. The heterozygous group has a much higher mean and also a much wider range in coefficients of variability.

The range in spike density of the homozygous dense group of F_3 progenies is from 1.63 ± 0.10 millimeters to $2.37 \pm .23$ millimeters per rachis internode. The most dense of the IIIC 18 parent rows is $2.41 \pm .22$ millimeters which, it will be observed, is less dense than the least dense of the homozygous dense progenies. The head density of IIIC 18 was not recovered in a single progeny. This is rather a peculiar situation which has occurred before in spike density inheritance in crosses involving Sevier, and which is as yet unexplained.

The spike density range in the homozygous lax progenies transgresses the range of the Federation parent. Federation ranges from 4.66 ± 0.42 millimeters to 5.41 ± 0.18 millimeters per rachis internode while the homozygous lax progenies range from 4.34 ± 0.33 to 6.40 ± 0.49 millimeters.

The heterozygous progenies are intermediate between the two homozygous groups and overlap them in but a few cases.

The F_1 spike density was 2.2 mm. per rachis internode. The heterozygous F_3 progenies came from F_2 plants which ranged from 1.6 millimeter per rachis internode to 2.8 millimeters per rachis internode. A frequency curve of the F_2 parent plants ~~heterozygous for~~ which produced the three F_3 spike density groups is shown in Fig. 8 .

There were 80 homozygous dense, 171 heterozygous and 103 homozygous lax progenies. These numbers suggest a 1:2:1 ratio altho P = 0.1884 and indicates a rather poor fit. The goodness of fit is given in Table 6.

Table 6. Goodness of fit for three groups of F_3 progenies for spike density compared with a 1:2:1 ratio

(Grown in 1927 at Logan, Utah)

Group	C	O	C - O	$(C - O)^2$	$\frac{(C - O)^2}{C}$
Homozygous Dense	88.5	80	8.5	72.25	.8164
Heterozygous	177.0	171	6.0	36.00	.2034
Homozygous Lax	88.5	103	14.5	210.25	2.3757

$X^2 = 3.3955$

P = .1884

There is probably one major factor difference for spike density and there may be some minor factors which modify this inheritance. This would seem to be indicated by the transgressive segregation which fails to recover the III C 18 parental head density and by the rather wide range in the homozygous progenies of both homozygous groups.

Awn Length

When first securing the data on the F_3 progenies it was thought to be unnecessary to measure the short tip awns found on awn Class 1 plants. After about 90 of the progenies had been worked it was decided that this figure would be useful. The Number 1 awns were measured for the remainder of the progenies. Only the progenies in which all awn classes present were measured were used in making calculations of awn length data. Since there was a fair representation in each awn class group after eliminating the progenies in which Number 1 awns were not measured, it is believed that the tables and calculations represent the material fairly accurately.

Table 7 shows the arrangement in awn length classes and standard deviation classes(S.D.) of the 9 awn class genotypes. Standard deviation instead of coefficient of variability was used in studying awn length, because it seemed better to represent the true condition of the material. For example a homozygous awn class 1 progeny would show a low standard deviation, but because of the low mean awn length the coefficient of variability when calculated would be high.

The four homozygous awn classes show a small range in standard deviation (S.D.) classes and also in mean standard deviation.

Awn	class	1	ranges	from	1.43 to 3.64 mm.	with	a mean	of	3.17	mm.
"	"	2	"	"	2.36 to 6.30 "	"	"	"	4.43	"
"	"	3	"	"	5.03 to 9.86 "	"	"	"	7.70	"
"	"	4	"	"	5.19 to 12.01 "	"	"	"	8.40	"

Table 7. Awn length classes of the means of parental rows and of F_3 progenies and standard deviation(S.D.) classes of the individual rows of each parent and of the nine awn class genotype groups of the F_3 progeny.

(Grown in 1927 at Logan, Utah)

	Awn Length Classes																			
Awn Class	2.5	7.5	12.5	17.5	22.5	27.5	32.5	37.5	42.5	47.5	52.5	57.5	62.5	67.5	72.5	77.5	82.5	Total	S.D. Classes	Total Number of Individuals
Federation	11	3																14	2	
		10																10	4	24
Total	11	13																Mean	2.93	
III C - 18															4	1	1	6	6	
														2	11	7		20	8	
														1	7			8	10	37
															1			1	12	
														1	1			2	14	
Total														4	24	8	1	Mean	8.54	
omozygous	7																	7	2	
Awn #1	2	1																3	4	10
Total	9	1																Mean	2.17	
	1																	1	2	
Segregating	3	7																10	4	
Awn # 1 & 2		10	1															11	6	28
		5	1															6	8	
Total	4	22	2															Mean	5.52	
			3	2														5	2	
omozygous			5	6														11	4	23
wn #2				7														7	6	
Total			8	15														Mean	4.43	
				1														1	6	
egregating			1															1	8	
wn #1,2,3			6		1													7	10	
			2															2	12	24
			3															3	14	
			2	6	1													9	16	
				1														1	18	
Total			14	8	2													Mean	12.92	
				1														1	12	
				2	1		1											4	14	
egregating				7		1												8	16	
wn #1,2,3,4				3	4													7	18	48
				4	6	3												13	20	
					1	4												5	22	
				1	2	2												5	24	
						1	2											3	26	
							1	1										2	28	
Total				18	14	11	4	1										Mean	19.74	
					3	5												8	6	
omozygous						4	3	2	3									12	8	24
wn #3						1	2		1									4	10	
Total					3	10	5	2	4									Mean	7.70	

Table 7. Continued

Awn Class	Awn Length Classes																	Total	S.D. Classes	Total Number of Individuals
	2.5	7.5	12.5	17.5	22.5	27.5	32.5	37.5	42.5	47.5	52.5	57.5	62.5	67.5	72.5	77.5	82.5			
egregation								1										1	8	
Awn #2,3,4																			10	
							1			1								2	12	
							1		1									2	14	
						1	2	1	1	1								6	16	
						2	1	3										6	18	43
					1		2	4	3									10	20	
							3	3	3									9	22	
									1									1	24	
							1	2			1							4	26	
									1									1	28	
										1								1	30	
Total					1	3	11	14	10	3	1							Mean	19.56	
								1	4									5	12	
egregating							1		1	3	3							8	14	
Awn #3,4								2	2	5	2	1						12	16	
										3	2	2						7	18	38
								1			2							3	20	
																			22	
												2	1					3	24	
Total							1	4	7	11	9	5	1					Mean	16.36	
mozygous											1	1	3	1				6	6	
Awn #4												2	1			4	1	8	8	
									1			1	1	3		1	1	8	10	23
													1					1	12	
Total									1		1	4	6	4		5	2	Mean	8.40	

The segregating awn classes all show a greater range and a higher mean standard deviation except the awn 1 and 2 segregating class. It is to be expected that the longer awned classes would show a greater range and higher mean standard deviation than the shorter awned classes. This is borne out in the figures. The standard deviation(S.D.) range and mean for the segregating groups was:

Segregating for	Range	Mean
Awn 1, 2	2.07 to 8.32 mm.	5.52 mm.
Awn 1, 2, 3	6.57 to 17.08 mm.	12.92 mm.
Awn 1, 2, 3, 4	12.79 to 28.53 mm.	19.74 mm.
Awn 2, 3, 4	8.71 to 29.32 mm.	19.56 mm.
Awn 3, 4	11.63 to 24.74 mm.	16.36 mm.

These higher(S.D.) tend to show that eye classification of awn classes was fairly accurate.

In awn length the range of homozygous awn 1 progenies practically covers the range of the Federation parent.

The awn 1 progeny range is from 2.35 ± .96 millimeters to 5.39 ± 2.46 millimeters. Federation ranges from 3.56 ± 1.38 to 6.62 ± 2.77 millimeters. The homozygous awn 4 progenies transgress, in one direction but not the other, the range of III C 18, the fully awned parent.

The awn 4 progenies range from 42.52 ± 7.35 millimeters to 80.40 ± 4.89 millimeters in awn length, while the III C 18 rows range from 67.20 ± 9.30 to 84.50 - 3.84 millimeters.

The homozygous awn 2 progenies range from 11.28 ± 1.59 to 19.68 ± 3.94 millimeters in awn length. The homozygous awn 3 range is from 22.12 ± 3.71 to 42.15 ± 6.65 millimeters.

The segregating groups are arranged intermediately between the homozygous groups for awn length. Segregating group awn 1, 2 is intermediate between homozygous awn 1 and homozygous awn 2 in awn length. Segregating group awn 1, 2, 3 and segregating group awn 1, 2, 3, 4 are intermediate between homozygous awn 2 and homozygous awn 3. Segregating group awn 2, 3, 4 and segregating group awn 3, 4 are intermediate between homozygous awn 3 and homozygous awn 4.

Awn Class and Spike Density Factors Probably not Linked

Stewart(5) in a cross of Kanred by Sevier obtained good correlation between awn length and spike density characters also(3) in a cross of Federation x Sevier he obtained consistent correlation ratios(6) when spike density and awn classes were correlated. These results led to the belief that there was linkage between spike density and awn class factors.

In studying the present cross(Federation x III C-18) with respect to linkage for spike density and awn class factors, there are two points that should be borne in mind. First, awn class as separated by eye classification is a distinct and separate character from awn length. There might be a high correlation between awn length and another plant character while the correlation between awn classes and the same plant character could be essentially zero. Different awn class groups may have awn length correlated with a given plant character in quite different degrees as will be seen later in this discussion.

Second, the awn class inheritance in the Federation x III C-18 cross is different from that of Federation x Sevier cross as has been already shown. Inheritance in the former showed independent segregation on a two factor difference basis while that of the latter showed rather definite linkage with only 35 per cent of crossing over.

In order to determine whether or not there was linkage between awn class and spike density factors the F_3 progenies were arranged into 27 genotype classes which would occur in independently segregating material where three factor differences are involved. Table 8 shows the genetic constitution of each of the 27 classes and

Table 8. Goodness of fit of 27 awn class and spike density genotype classes of F_3 progenies when compared with the theoretical ratio of independent segregation with three factor differences. (L) = lax spike and (l) dense spike.

(Grown in 1927 at Logan, Utah)

	Genotype	C	O	C - O	$(C - O)^2$	$\frac{(C - O)^2}{C}$
1	AA BB LL	5.53	6	.47	.2209	.0399
2	AA BB Ll	11.06	9	2.06	4.2436	.3837
3	AA Bb LL	11.06	8	3.06	9.3636	.8466
4	Aa BB LL	11.06	12	.94	.8836	.0799
5	AA Bb Ll	22.12	26	3.88	15.0544	.6806
6	Aa BB Ll	22.12	23	.88	.7744	.0350
7	Aa Bb LL	22.12	24	1.88	3.5344	.1598
8	Aa Bb Ll	44.24	38	6.24	38.9376	.8801
9	AA BB ll	5.53	8	2.47	6.1009	1.1032
10	AA Bb ll	11.06	4	7.06	49.8436	4.5067
11	Aa BB ll	11.06	8	3.06	9.3636	.8466
12	Aa Bb ll	22.12	19	3.12	9.7344	.4401
13	AA bb LL	5.53	10	4.47	19.9809	3.6132
14	AA bb Ll	11.06	8	3.06	9.3636	.8466
15	Aa bb LL	11.06	15	3.94	15.5236	1.4036
16	Aa bb Ll	22.12	19	3.12	9.7344	.4401
17	aa BB LL	5.53	5	.53	.2809	.0508
18	aa BB Ll	11.06	13	1.94	3.7636	.3403
19	aa Bb LL	11.06	16	4.94	24.4036	2.2065
20	aa Bb Ll	22.12	27	4.88	23.8144	1.0766
21	AA bb ll	5.53	6	.47	.2209	.0399
22	Aa bb ll	11.06	12	.94	.8836	.0799
23	aa BB ll	5.53	6	.47	.2209	.0399
24	aa Bb ll	11.06	7	4.06	16.4836	1.4904
25	aa bb LL	5.53	7	1.47	2.1609	.3908
26	aa bb Ll	11.06	8	3.06	9.3636	.8466
27	aa bb ll	5.53	10	4.47	19.9809	3.6132
	Total	353.92	354			

X^2 = 25.4806

P = .4375

also the goodness of fit when compared to the theoretical numbers which would be expected in a three factor difference cross with independent segregation. The factor for lax spike is designated by L and its allelomorph dense spike by l. The awn classes have the same designation as before given.

For the 27 classes X^2 = 26.4806 and P = .4373. This is a good fit and indicates that there is at least no strong linkage between spike density and awn class characters in the Federation x III C-18 cross.

Correlations

Parents

Correlations were calculated for the Federation and the adjacent III C-18 parental rows. The correlation coefficients, their probable errors and the r/PE are given in Table 9.

Table 9. Correlation coefficients(r) and their respective probable errors and r/PE for the pairs of parent rows when various plant characters were used.

(Grown in 1927, at Logan, Utah)

Character	r - P.E.	$\frac{r}{P.E.}$
Culm Length	+.5082 ± .0318	16.0
Spike Density	+.0865 ± .110	0.8
No. of Culms	- .4770 ± .0857	5.6
Awn Length	+.0093 ± .1377	0.1
Neck Thickness	+.1240 ± .1092	1.1

Table 10. Correlation coefficients(r) and their respective probable errors(P.E.) and r/P.E. for pairs of plant characters with each parent.

(Grown in 1927 at Logan, Utah)

Plant Characters	r ± P.E.	$\frac{r}{P.E.}$
Federation		
Culm Length x Spike Density	- .0118 ± .1093	0.1
Spike Density x Neck Thickness	+ .6373 ± .0658	9.7
III C-18		
Culm Length x Spike Density	- .2436 ± .1045	2.3
Spike Density x Neck Thickness	+ .1877 ± .1070	1.8

The high positive correlation coefficient(r) obtained when the adjacent parental rows were correlated for culm length probably indicates the degree to which soil heterogeneity influenced this character. The large minus correlation coefficient(r) obtained when number of culms per plant was considered probably indicates the degree of competition which entered in between the two parents. Spike density(r = + .0865 ± .110), awn length (r = + .0093 ± .1377) and neck thickness(r = + .1240 ± .1092) seem to be more stable characters which are less influenced by environmental factors as shown by their low correlation coefficients(r).

Correlation coefficients(r) were calculated for two pairs of plant characters studied with each parent. These constants with their probable errors are given in Table 10.

Culm length x spike density in the Federation parent rows gave a correlation coefficient(r) which is only 1/10 of its probable error. (r = - .0118 ± .1093). These same two characters in the III C-18 give a correlation coefficient(r) which is of little significance since it is not large and is only 2.3 times its probable error ($r = -.2436 \pm .1043$). In neither of the parents does there seem to be a definite relation between culm length and spike density.

When spike density x neck thickness was correlated in the Federation the correlation coefficient (r) was large and was 9.7 times its probable error. ($r = +.6373 \pm .0658$). These same characters in the IIIC 18 gave a low correlation coefficient (r) which was only 1.8 times its probable error ($r = +.1877 \pm .1070$). Spike density and neck thickness are distinctly correlated in the Federation parent. A laxer head tends to go with a thicker neck. This relationship is less definite with the denser spiked parent, IIIC 18.

Correlation Studies With The F_3 Progenies

Ten pairs of combinations of the five plant characters were possible in the correlation studies. The simple correlation coefficients (r), the correlation ratios (n) and B.T. were calculated for all ten pairs of plant characters. The ten combinations are:

1. Culm length x spike density
2. Culm length x awn length
3. Culm length x neck thickness
4. Culm length x number of culms
5. Spike density x awn length
6. Spike density x neck thickness
7. Spike density x number of culms
8. Awn length x neck thickness
9. Awn length x number of culms
10. Neck thickness x number of culms

These constants with their probable errors and $\frac{r}{P.E.}$ are given in Table 11.

The partial correlation coefficients were also calculated for the six pairs of characters which could be combined when number of culms character was omitted. These constants together with the simple product moment correlation coefficients (n) and their probable errors (P.E.) are given in Table 12.

Culm Length X Spike Density

While the F_3 material was being worked the observation was made that F_3 progenies which were homozygous for dense spikes tended to have short straw or low culm length and that progenies homozygous for lax spikes tended to have long culm length. The large correlation coefficient (r) for culm length x spike density bears this observation out, r = .5198 ± .0262. The constant is 19.8 times its probable error. The partial correlation coefficient given in Table 12 is also high (r 12.34 = +.5006 ± .0268) and is 18.7 times its probable error. The high partial correlation coefficient indicates that the correlation is a real one and not a carry over from other related characters. The correlation ratio (n) is only slightly larger than r and Blakeman's test for linearity is only 2.3740 which indicates that the correlation is essentially linear in its nature.

Since this pair of characters when correlated in each of the two parents (Table 10) showed no significant constants it was thought advisable to study the F_3 progenies more completely to determine if possible the nature of the relationship existing. In order to do this the F_3 progenies were divided into their three spike density groups, (1) homozygous dense, (2) heterozygous, and (3) homozygous lax. Correlations for culm length x spike density were then calculated for each of the three groups independently. The correlation coefficients (r) their probable erros (P.E.) and $\frac{r}{P.E.}$ are given in Table 13.

Table 11. Correlation coefficients(r), correlation ratios(n), their respective probable errors(P.E.), and Blakeman's test for linearity for various pairs of plant characters for 354 F_3 progenies.

(Grown in 1927 at Logan, Utah)

Characters Correlated	r ± P.E.	$\frac{r}{P.E.}$	n ± P.E.	$\frac{n}{P.E.}$	B.T.
Culm Length x Spike Density	+.5198 ±.0262	19.8	.5344 ±.0256	20.9	2.3740
Culm Length x Awn Length	+.0584 ±.0417	1.4	.2993 ±.0381	9.2	3.5096
Culm Length x Neck Thickness	+.1974 ±.0345	5.7	.2538 ±.0335	7.6	2.2263
Culm Length x No. of Culms	+.0521 ±.0357	1.5	.1824 ±.0347	5.3	2.4427
Spike Density x Awn Length	-.1112 ±.0413	2.7	.3496 ±.0367	9.5	3.9641
Spike Density x Neck Thickness	+.4490 ±.0286	15.7	.5711 ±.0241	23.7	4.9302
Spike Density x No. Culms	+.0967 ±.0355	2.9	.1833 ±.0346	5.3	2.1760
Awn Length x Neck Thickness	-.2874 ±.0384	7.5	.4068 ±.0349	11.7	3.4458
Awn Length x No. of Culms	+.0343 ±.0418	.8	.3107 ±.0378	8.2	3.6925
Neck Thickness x No. of Culms	+.0265 ±.0358	.7	.1755 ±.0347	5.1	2.4232

Table 12. Simple product-moment correlation coefficients(r) comparative partial correlation coefficients and their respective probable errors for 354 F_3 progenies.

(Grown in 1927 at Logan, Utah)

Characters Correlated	r ± P.E. (Simple)	r / P.E.	r Sub.	± P.E. (Partial)	r / P.E.
Culm Length x Spike Density	+.5198 ±.0262	19.8	r 12.34	+.5006 ±.0268	18.7
Culm Length x Awn Length	+.0584 ±.0417	1.4	r 13.24	+.1292 ±.0353	3.7
Culm Length x Neck Thickness	+.1974 ±.0345	5.7	r 14.23	+.0110 ±.0358	0.3
Spike Density x Awn Length	-.1112 ±.0413	2.7	r 23.14	+.0364 ±.0358	1.0
Spike Density x Neck Thickness	+.4490 ±.0286	15.7	r 24.13	+.3946 ±.0303	13.0
Awn Length x Neck Thickness	-.2874 ±.0384	7.5	r 34.12	-.2637 ±.0389	6.8

1 = Culm length
2 = Spike density
3 = Awn length
4 = Neck thickness

Table 13. Correlation coefficients(r) and probable errors(P.E.) for culm length x spike density in each of the three spike density groups of the F_3 progenies.

(Grown in 1927 at Logan, Utah)

Group	$r \pm$ P.E.	$\frac{r}{P.E.}$
Homozygous Dense	+.2454 ±.0709	3.5
Heterozygous	+.1193 ±.0509	2.3
Homozygous Lax	-.1612 ±.0648	2.5

Two of the groups, homozygous dense ($r = + .2454 \quad .0709$) and heterozygous ($r = + .1193 \pm .0509$) show comparatively small plus correlation coefficients and the third group, homozygous lax, shows a small minus correlation coefficient ($r = - .1612 \pm .0648$). The largest constant of the three is only 3.5 times its probable error. These constants indicate that the large correlation coefficient ($r = .5198 \pm .0262$) obtained when the entire 354 F_3 progenies were included is probably between groups (homozygous dense, heterozygous and homozygous dense) rather than within the groups.

The correlation here does not seem to be due to a physiological relationship between culm length and spike density since neither of the parents show a significantly high correlation coefficient and also since neither of the spike density groups show a significant correlation coefficient.

The other explanation which might be suggested is that there is linkage of some sort between culm length and spike density factors. Lax spiked progenies tend also to be tall progenies and dense spiked progenies tend also to be short progenies. If linkage does exist the nature of it would be difficult to explain since the parental forms bring the characters into the corss in the opposite combination from that shown in the progenies. The lax spiked parent (Federation) is the short parent and the dense spiked parent (III C 18) is the tall parent. It has already been noted that spike density inheritance is rather complicated. Culm length inheritance is probably just as complicated.

Culm Length X Awn Length

The correlation coefficient (r) between culm length and awn length is small ($+ .0584 \pm .0417$) and is only 1.4 times its probable error. So far as r can measure no correlation exists between these characters. The parental correlation coefficient ($r_{13.24} = +.1292 \pm .0354$) is somewhat larger and is 3.7 times its probable error. This constant suggests that there is some relationship which other correlated characters have hidden. The correlation ratio $(n) = .2993 \pm .0381$ and is 9.2 times its probable error. This constant together with the rather high figure determined for Blakeman's test for linearity (B.T. = 3.5096) points to the existence of a correlation which r is unable to measure. The nature of this correlation was more fully determined and is given later in the discussion.

Culm Length X Neck Thickness

The correlation coefficient obtained for these two factors was $+.1974 \pm .0345$. The constant is 5.7 times its probable error. However, the partial correlation coefficient was only $+.011 \pm .0358$ which indicates that the r obtained was probably a carry-over from other correlated characters.

The correlation ratio obtained ($n = .2538 \pm .0335$) is 7.6 times its probable error. Since Blakeman's test (B.T. = 2.2263) is small, n is probably not very significant.

Culm Length X No. of Culms

The correlation coefficient obtained for these characters is very small ($r = +.0521 \pm .0357$) and is only 1.5 times its probable error. The partial correlation coefficient was not calculated.

The correlation ratio obtained ($n = .1824 \pm .0347$) is not significant when viewed in connection with the small Blakeman's test obtained (B.T. = 2.4427).

Spike Density X Awn Length

For these characters the correlation coefficient obtained ($r = -.112 \pm .0413$) is small and is only 2.7 times its probable error. The partial correlation coefficient ($r_{23.14} = -.0364 \pm .0358$) indicates that the correlation obtained by r is the carry-over from other characters.

The correlation ratio ($n = .3496 \pm .0367$) is fairly good sized and is 9.5 times its probable error. Blakeman's test (B.T. = 3.9641) is also fairly high. These two constants suggest a correlation which r fails to measure. This correlation was at least partly located in the family and is reported later.

Spike Density X Neck Thickness

The correlation coefficient for these two characters is high enough to be significant ($r = + .449 \pm .0286$ and $\frac{r}{P.E.} = 15.7$). The good partial correlation coefficient shows that the correlation is real and not a carry-over from related characters. Partial $r_{24.13} = +.3946 \pm .0303$ and is 13 times its P.E. A rather high correlation ratio ($n = .5711 \pm .0241$ and $\frac{n}{P.E.} = 23.7$), and a good Blakeman's test for linearity, (B.T. = 4.9302) both suggest that there is considerable correlation which r fails to measure.

Each of the two parents were correlated for these same two characters. The mean values for each of the 37 rows were used in calculating the correlations. Federation gave a correlation coefficient of $+ .6373 \pm .0658$ and $\frac{r}{P.E.} = 9.69$. For III C 18, $r = + .1877 \pm .1070$ and $\frac{r}{P.E.} = 1.75$. The laxer of the two parents give a good plus correlation. The dense parent gave a plus correlation which is too small to be of much significance.

In order to study these characters more fully correlation coefficients were calculated for them in each of the three spike density groups (homozygous dense, heterozygous and homozygous lax). The coefficients of correlation with their probable errors are given in Table 14.

The correlation coefficient for homozygous dense ($r = .3917 \pm .0638$) is 6.1 times its probable error. For the heterozygous ($r = + .2612 \pm .0481$) the constant is 5.4 times its probable error. For the homozygous lax

Table 14. Correlation coefficients(r) and probable errors(P.E.) for spike density in each of the three spike density groups of F_3 progenies.

(Grown in 1927 at Logan, Utah)

Group	r ± P.E.	r/P.E.
Homozygous Dense	+.3917 ±.0638	6.1
Heterozygous	+.2612 ±.0481	5.4
Homozygous Lax	+.6915 ±.0347	19.19

($r = + .6915 \pm .0347$) the constant is 19.9 times its probable error. While these coefficients are all plus and all high enough to be significant there is a wide difference between the lowest and the highest. It is in measuring this spotted or curvilinear condition in a population that n is particularly valuable.

Plus correlation coefficients were obtained then, for the entire family for both parents and for each of the three spike density groups. All were high enough to be significant except the III C 18 constant. Spike density and neck thickness are then positively correlated. The laxer the spike the thicker the neck and the denser the spike the thinner the neck. This relationship seems to be much stronger in the lax spiked group of the progeny and in the lax spiked parent than in the denser spiked groups.

Since this relationship exists within the spike density groups and with at least one of the parents it is thought to be a physiological rather than a genetic relationship.

Spike Density and Number of Culms

These characters gave a small correlation coefficient ($r = +.0967 \pm .0355$ and $\frac{r}{P.E.} = 2.9$) The correlation ratio was some higher but not significantly so $n = .1833 \pm .0346$ and $\frac{r}{P.E.} = 53$. Blakeman's test for linearity gives 2.1760. The correlation coefficient was so low that partial correlation coefficient was not calculated.

Awn Length X Neck Thickness

The correlation coefficient for these characters is $-.2874 \pm .0384$. This correlation is 7.5 times its P.E. The correlation ratio = $.4068 \pm .0349$. It is 11.7 times its P.E. Blakeman's test for linearity is 3.4438. The partial correlation coefficient is $-.2637 \pm .0389$ and is 6.8 times its P.E. These constants are all large enough to suggest a real negative correlation between the characters of awn length and neck thickness. The nature of these characters make it impossible to determine whether or not the correlation is due to linkage.

<u>Awn Length X Number of Culms</u>

The correlation coefficient for these characters is + .0343 ± .0418. The P.E. is larger than its constant. However the correlation ratio is .3107 ± .0378 and is 8.2 times its P.E. and Blakeman's test is 3.6926. These latter figures suggest that there is a correlation which r cannot measure. Partial correlation coefficient was not calculated.

<u>Neck Thickness X Number of Culms</u>

Correlation coefficient is + .0265 ± .0358. It is smaller than its P.E. The correlation ratio (n = .1755 ± .0347) is 5.1 times its P.E. Blakeman's test = 2.4232. Partial correlation coefficient was not calculated.

<u>Multiple Correlations</u>

In order to determine the proportion of the variability in each character which the other characters accounted for, the multiple correlation coefficient was calculated. These constants are given in Table 15. The constants are changed into percentage by using the formula $V (\%) = 100 \times 1 - \sqrt{1 - r^2}$. The percentage is also given in Table 15.

Culm length multiple correlation coefficient is expressed by R 1.234 = .5328. This changed to percentage = 15.38. The variables spike density, awn length, and neck thickness account for 15.38 per cent of the total variability of culm length. There is, then, 84.62 per cent of the variability of culm length which is unaccounted for.

Spike density or R 2.134 = .6388 or 23.06 per cent. The other variables account for 23.06 per cent of the variability of spike density.

Table 15. Multiple correlations showing the total effect of variability caused by the other three plant characters on the respective one indicated for 354 F_3 progenies.

(Grown in 1927 at Logan, Utah)

Plant Characters	Multiple Correlation	Correlation Coefficient	Percentage of Total Variability Accounted for
Culm Length	R1.234	.5328	15.38
Spike Density	R2.134	.6388	23.06
Awn Length	R3.124	.3135	5.04
Neck Thickness	R4.123	.5087	13.91

Awn length or R $3.124 = .3135$. The other variables account for only 5.04 per cent of the variability in awn length.

Neck thickness or R$4.123 = .5087$. The percentage of variability accounted for here by the other variables is 13.91.

Correlation Studies With the Four Homozygous Awn Classes

In the correlation studies which have been so far discussed it was noted in several instances that there was a considerable difference between the two constants (r) and (n). Also that Blakeman's test was often significantly high. These facts indicated that there was some correlation which r could not measure but which n was able to account for.

In order to discover if possible, where this correlation occurred, each of the four homozygous awn class progenies, Awns 1, Awns 2, Awns 3, and Awns 4 were studied. The correlation coefficients and also the partial correlation coefficients in each group were calculated for most of the pairs of characters that were correlated when the 354 F_3 progenies were studied as a group.

Because part of the progenies in awn class 1 group had not been measured for awn length it was impractical to calculate correlations involving awn length in this group. This makes three pairs of factors which were correlated here.

1. Culm length X spike density

2. Culm length X neck thickness

3. Spike density X neck thickness

In awn class 2, awn class 3 and awn class 4 there were six pairs of characters correlated.

1. Culm length X spike density

2. Culm length X awn length

3. Culm length X neck thickness

4. Spike density X awn length

5. Spike density X neck thickness

6. Awn length X neck thickness

A summary of simple product moment correlation coefficients and partial correlation coefficients with their respective probable errors is given in Table 16.

Culm Length X Spike Density

The correlation coefficients (r) for each of the four awn groups except Awn 2 group are fairly high and hence bear out the correlation obtained when all the F_3 progenies were studied as a group. Awn 2 is not high but is suggestive. The constants for each of the awn groups are: Awn 4 = +.4857 ± .1074 and $\frac{r}{P.E.}$ = 4.5; Awn 3 = + .5584 ± .0948 and $\frac{r}{P.E.}$ = 5.9; Awn 2 = + .2750 ± .1300 and $\frac{r}{P.E.}$ = 2.1; Awn 1 = + .7991 ± .0488 and $\frac{r}{P.E.}$ = 16.4.

The partial correlation coefficient for Awn 4 is lower than its simple product moment correlation coefficient (r 12.34 = +.2480 = .1320 and $\frac{r}{P.E.}$ 1.9) Awn 3 and Awn 2 groups however, show a considerably higher partial correlation coefficient than their simple correlation coefficients (Awn 3, r12.34 = +.6909 ± .072 and $\frac{r}{P.E.}$ = 9.6) and (Awn 2, r 12.34 = + .6206 ± .9865 and $\frac{r}{P.E.}$ = 7.2) Partial correlation coefficients were not calculated for Awn 1 group.

It was earlier shown that the correlation between spike density and culm length was essentially between the spike density groups and not within them. Any four random samplings of the F_3 progenies in which23 to 25 progenies were taken would probably show about the same variability in correlation coefficients

Table 16. Simple product moment correlation coefficients(r) comparative partial correlation coefficient and their respective probable errors for each of the 4 homozygous awn class groups of F_3 progenies(awn 4, awn 3, awn 2, and awn 1)

(Grown in 1927 at Logan, Utah)

Characters Correlated	Simple r ± P.E.	r/P.E.	Partial r ± P.E.	r/P.E.
Awn 4				
Culm Length x Spike Density	+.4857 ±.1074	4.5	r 12.34 = +.2480 ±.1320	1.9
Culm Length x Awn Length	+.7226 ±.0672	10.8	r 13.24 = +.6166 ±.0871	7.1
Culm Length x Neck Thickness	+.4737 ±.109	4.3	r 14.23 = +.2100 ±.1344	1.6
Spike Density x Awn Length	+.7857 ±.0538	14.6	r 23.14 = +.6763 ±.0763	8.9
Spike Density x Neck Thickness	+.5867 ±.0922	6.4	r 24.13 = +.3413 ±.1242	2.7
Awn Length x Neck Thickness	+.5451 ±.0989	5.5	r 34.12 = +.00028 ±.1406	
Awn 3				
Culm Length x Spike Density	+.5584 ±.0948	5.9	r 12.34 = +.6909 ±.0720	9.6
Culm Length x Awn Length	+.0232 ±.1376	0.2	r 13.24 = +.1233 ±.1356	.9
Culm Length x Neck Thickness	-.0315 ±.1375	0.2	r 14.23 = -.4807 ±.1059	4.5
Spike Density x Awn Length	+.2162 ±.1313	1.6	r 23.14 = +.2017 ±.1321	1.5
Spike Density x Neck Thickness	+.5697 ±.0930	6.1	r 24.13 = +.7011 ±.0700	10.0
Awn Length x Neck Thickness	+.1462 ±.1348	1.1	r 34.12 = +.0387 ±.1375	.3

Table 16. Continued.

Characters Correlated	Simple r ± P.E.	r/P.E.	Partial r ± P.E.	r/P.E.
Awn 2				
Culm Length x Spike Density	+.2750 ±.1300	2.1	r 12.34 = +.6206 ±.0865	7.2
Culm Length x Awn Length	-.0075 ±.1406	.05	r 13.24 = -.1396 ±.1379	1.0
Culm Length x Neck Thickness	-.4676 ±.1099	4.3	r 14.23 = -.6954 ±.0726	9.6
Spike Density x Awn Length	+.0382 ±.1404	.3	r 23.14 = +.1204 ±.1386	.9
Spike Density x Neck Thickness	+.4492 ±.1122	4.0	r 24.13 = +.6849 ±.0747	9.2
Awn Length x Neck Thickness	+.1709 ±.1365	1.3	r 34.12 = +.2195 ±.1339	1.6
Awn 1				
Culm Length x Spike Density	+.7991 ±.0488	16.4		
Culm Length x Neck Thickness	+.6777 ±.0729	9.3		
Spike Density x Neck Thickness	+.5924 ±.0876	6.8		

1 = Culm Length
2 = Spike Density
3 = Awn Length
4 = Neck Thickness

that the four awn groups show since each spike density group would probably be represented.

Culm Length X Awn Length

When the entire group of 354 F_3 progenies was being studied, the correlation coefficient was very small and only slightly larger than its probable error ($r = + .0584 \pm .0417$). The partial correlation was suggestive ($r13.24 = + .1292 = .0353$ with $\frac{r}{P.E.} = 3.7$) and the correlation ratio (n) and Blakeman's test indicated that there was probably significant correlation somewhere within the group ($n = .2993 \pm .0381$ and $\frac{r}{P.E.} = 9.2$) (B.T. = 3.5096).

By a correlation study with the awn class groups the correlation which n indicates was partly located. Awn 4 gives a high correlation coefficient ($r = + .7226 \pm .0672$) which is 10.8 times its probable error and also a high partial correlation coefficient ($r = +.616 \pm .0871$) which is 7.1 times its probable error. Awn 3 ($r = .0232 \pm .1376$) and (Awn 2 ($r = -.0073 \pm .1406$) give very low correlation coefficients which in both cases are considerably below their probable errors. Their partial correlation coefficients are also low and essentially equal to their probable errors. (Awn 3, $r\,13.24 = .1233 \pm .1356$) and (Awn 2, $r13.24 = .1396 \pm .1379$).

The correlation existing which n measures seems to be located in fully awned progenies but not in progenies of other awn classes.

Culm Length X Neck Thickness

Awn 4 group has a fairly high plus correlation coefficient ($r = + .4737 \pm .109$ and $\frac{r}{P.E.} = 4.3$). Its partial correlation is low ($r14.23 = .2100 \pm .1344$ and $\frac{r}{P.E.} = 1.6$). Awn 3 has a correlation coefficient lower than its probable error ($r = -.0315 \pm .1375$) yet its partial correlation coefficient is significantly high ($r14.23 = -.4807 \pm .1059$) and is 4.5 times its probable error. Awn 2 has a rather high minus correlation coefficient ($r = -.4676$ $.1099$) which is 4.3 times its probable error. Its partial correlation coefficient is still higher. ($r_{14.23} = -.6954 \pm .0726$ and $\frac{r}{P.E.} = 9.6$). Awn 1 group has a high plus correlation coefficient ($r = +.6777 \pm .0729$). It is 9.3 times its probable error.

Two of the groups then, show significant plus correlations when both simple product moment and partial correlation coefficients are observed. One of the other two groups shows a high minus correlation coefficient and the other a very small minus correlation coefficient which becomes large when the partial correlation coefficient is calculated. It is apparent that since two of these correlations are rather high plus and two are rather high minus that they would tend to balance each other when r was calculated for the entire family so that a small r would be obtained. This is what happened in this case. However, n was able to indicate the correlation which existed .

Spike Density X Awn Length

These plant characters when studied in the entire family of 354 progenies seemed not to be correlated when r and partial r were calculated but gave a high correlation ratio ($n = .3496 \pm .0367$) and a high Blakeman's test (B.T. = 3.9641). The correlation coefficients for the four awn groups are:

Awn 4 Group:

Simple correlation coefficient ($r = +.7857 \pm .0538$ and $\frac{r}{P.E.} = 14.6$

Partial Correlation coefficient($r_{23.14} = +.6763 \pm .0763$ and $\frac{r}{P.E.} = 8.9$

Awn 3 Group:

Simple Correlation coefficient($r = +.2162 \pm .1313$ and $\frac{r}{P.E.} = 1.6$

Partial correlation cefficient($r_{23.14} = .2017 \pm .1321$ and $\frac{r}{P.E.} = 1.5$

Awn 2 Group:

Simple correlation coefficient ($r = + .0382 \pm .1404$ and $\frac{r}{P.E.} = 0.3$

Partial correlation coefficient $r\ 23.14 = + .1204 \pm .1386$ and $\frac{r}{P.E.} = 0.9$

The correlation that exists here seems to be located again, as was the correlation between culm length and awn length, in the fully awned group and to be lacking in the other awn groups studied.

Here again is demonstrated the value of n in indicating correlations which r cannot measure.

Spike Density X Neck Thickness

All the constants when these two characters were studied in the entire family of F_3 progenies indicated that there was a definite relationship and seemed to suggest that this relationship was physiological in its nature. The constants obtained when correlations were made with the four awn groups bears out this suggestion since in every group significant plus correlation coefficient was obtained both simple and partial. Awn 2 group gave the lowest correlation coefficient obtained ($r = + .4492 \pm .1122$) which is significantly high and which is four times its probable error. Awn 4 group gave the lowest partial correlation coefficient obtained ($r\ 24.13 = + .3413 \pm .1242$) which is high enough to be of some significance and which is 2.7 times its probable error.

All the data then, indicates that the laxer the spike the thicker the neck and the denser the spike the thinner the neck. Since this relationship occurs consistently with the entire family with the parents (although to a much less extent with III C 18, the denser parent) and with the four homozygous awn groups studied , the suggestion is that it may be a physiological relationship.

Awn Length X Neck Thickness

The correlation ratio ($n = .4068 \pm .0349$) and Blakeman's test (B.T. = 3.4438) obtained when the entire family of F_3 was studied, both suggest a correlation which r has failed to measure. A study of the 4 awn group throws no light on this. While awn 4 has a good correlation coefficient ($r = + .5451 \pm .0989$) its significance is destroyed when the partial correlation coefficient is found to be $r\ 34.12 = .00028 \pm .1406$.

Awn 3 correlation coefficient is $+ .1462 \pm .1348$ and a partial correlation coefficient of $.0387 \pm .1375$.

Awn 2 has a correlation coefficient of $+ .1709 \pm .1365$ and a partial correlation coefficient of $.2195 \pm .1339$.

While the correlations which n suggested have been located in several instances in this case the groupings that were studied failed to locate it.

Multiple Correlations

Multiple correlation coefficient (R) were calculated for each of three of the homozygous awn class groups, Awn 4, Awn 3, and Awn 2. These are given in Table 17. It may be noted that in general the variability of the various characters was influenced by the other variables more in the homozygous awn class groups than in the entire family. It may also be noted that in awn class 4 the other variables influence awn length to 48.96 per cent of its total variability while in awn class 3 this variable is influenced only 3.15 per cent by the other variables; in awn class 2 only 2.53 per cent; and in the entire family only 5.04 per cent.

It should be pointed out here that Stewart (5) worked with fully awned progenies (Kanred X Sevier cross) when he secured the high correlations between awn length and spike density characters.

Table 17. Multiple correlations showing the total effect of variability caused by the other three plant characters on the respective one indicated for 3 homozygous awn class groups (awn 4, awn 3, and awn 2).

(Grown in 1927 at Logan, Utah)

Plant Character	Multiple Correlation	Correlation Coefficients	Percentage of Total Variability Accounted for
		Awn 4 Group	
Culm Length	R1.234	.7483	33.67
Spike Density	R2.134	.8212	42.93
Awn Length	R3.124	.8599	43.96
Neck Thickness	R4.123	.6251	21.95
		Awn 3 Group	
Culm Length	R1.~~/~~234	.6919	27.80
Spike Density	R2.134	.8192	42.65
Awn Length	R3.124	.2490	3.15
Neck Thickness	R4.123	.7077	29.35
		Awn 2 Group	
Culm Length	R1.234	.7231	30.93
Spike Density	R2.134	.7142	30.01
Awn Length	R3.124	.2234	2.53
Neck Thickness	R4.123	.7747	36.76

Summary

III C 18 (a hybrid strain from a Sevier X Dicklow cross) and Federation were crossed. A vigorous F_1 family was chosen in the F_2 generation to continue with. Each F_2 plant seeded one F_3 progeny row. The rows were spaced one foot apart and the kernels in the row were spaced about three inches apart. Paired plantings of the two parents were made in the same manner and at the same time after each ten progeny rows.

Each F_3 progeny row was considered to represent the genetic constitution of its F_2 parent plant. (There were 354 F_3 progenies) Data were collected for the various plant characters studied by observation or by measurement.

Inheritance was studied ~~in rather considerable detail~~ for the following plant characters.

1. Color of glume
2. Awn class
3. Culm length
4. Spike density
5. Awn length
6. Neck thickness
7. Number of culms

Color of glume is inherited on the basis of a one factor difference. The numbers obtained were 82 bronze, 176 heterozygous and 96 white. These numbers closely approach a 1:2:1 ratio. P = .5782.

Awn class was thought to be inherited on the basis of a two factor difference with independent segregation. The numbers very closely approach the expected ratio on this hypothesis. (1:2:2:4:1:2:1:2:1) P = .9270 and indicates an extremely good fit.

Culm length of the F_3 progenies was correlated with their F_2 parents to the extent of + .4316 ± .0291. The culm length range in the parental rows was covered by the F_3 progeny.

Spike density inheritance was peculiar in its nature. Three spike density groups were found in the F_3 progeny; (1) homozygous dense, (2) heterozygous and (3) homozygous lax with the respective numbers for each group of 80, 171, and 103. These numbers suggest a 1:2:1 ratio with ~~but~~ the goodness of fit as indicated by P = .1884 ~~was not so high~~. The homozygous lax progenies transgress the range of the lax parent in mean spike density (mm. per rachis internode) (Federation). The dense parent III C 18 is not recovered in a single progeny. The homozygous dense progenies are all more dense than the most dense of the III C 18. The heterozygous progenies fall between the two homozygous progenies in spike density with no overlapping. There is probably a one factor difference with perhaps some minor factors involved in the spike density inheritance of this cross.

Awn length range of the parental rows was recovered in the F_3 progenies. Homozygous awn group 1 was essentially the same as Federation in awn length. Homozygous awn 4 group recovered the longest parental awn mean but transgressed the shortest parental awn mean several classes. The other awn classes were graduated in length in rather regular order between awn 1 and awn 4. Standard deviations were higher for the segregating awn class genotypes than for the homozygous awn classes.

Neck thickness was essentially the same for the two groups of parent rows. The range in the progenies was small.

Number of culms was essentially the same in both parents.

Awn class and spike density characters were studied together to determine whether or not linkage existed. The 354 F_3 progenies were arranged into 27 genotype groups which might bb expected on the hypothesis of independent segregation with three factor differences. Their numbers approached the expected numbers. When goodness of fit was calculated $P = .4373$ which is a good fit. This indicates that there is probably no linkage between spike density and awn class factors in this cross.

Product moment (r), partial and multiple correlation coefficients, correlation ratio, and Blakeman tests were calculated for various combinations of the following plant characters.

1. Culm length
2. Spike density
3. Awn length
4. Neck thickness
5. Number of culms

Culm length seems not to be correlated with spike density in either of the parents, nor in either of the three spike density groups; homozygous dense, heterozygous and homozygous lax. Yet when the correlation coefficient was calculated for the entire family of the F_3 progenies there was a significant correlation. These data indicate that the correlation is probably genetic.

Culm length and awn length are distinctly correlated in the homozygous fully awned progenies. The other homozygous awn class groups show no correlation. The entire family shows no correlation yet n ($n = .2993 \pm .0381$ and $\frac{n}{P.E.} = 9.2$)

and Blakeman's test (B.T. = 3.5096) both indicate the presence of one.

Spike density and awn length also seem to be correlated in the homozygous awn 4 group but not elsewhere. Also n again had already indicated that a correlation existed.

Spike density and neck thickness were found to be correlated in the Federation parent in the four homozygous awn groups studied, and in the entire family. Evidently the relationship here existing is physiological in its nature.

Multiple correlation coefficients were calculated for the entire family and for homozygous awn groups 4, 3 and 2 for the following plant characters:

1. Culm length
2. Spike density
3. Awn length
4. Neck thickness

The respective variables were influenced by the other variables to a less extent in the entire family than the homozygous awn class groups. Awn length variable was influenced 48.96 per cent of its total variability by the other variables in the awn 4 group. This same variable was influenced by the other variables only 3.15, 2.53, and 5.04 per cents in awn 3 group, awn 2 group and the entire family respectively.

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